Identification of the Memory Process in the Irregularly Sampled Discrete Time Signal of Solar Radio Flux

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***Abstract*- In the present work, we have considered the daily signal of Solar Radio flux of 2800 Hz cited by National Geographic Data Center, USA during the period from 29th October, 1972 to 28th February, 2013. We have applied Savitzky-Golay nonlinear phase filter on the present discrete signal to denoise it and after denoising Finite Variance Scaling Method has been applied to investigate memory pattern in this discrete time variant signal. Our result indicates that the present signal of solar radio flux is of short memory which may in turn suggest the multi-periodic and/or pseudo-periodic behaviour of the present signal.**

***Index Terms*- solar radio flux, Savitzky-Golay nonlinear phase filter, finite variance scaling method, Hurst exponent, short memory process.**

I. Introduction

From the recent studies of the solar radio flux emission it has been found that the mechanism involved in particle and free particle emission to ultimately understand the probable characteristics of the spectra of energetic particles, comprises of radio flux and the time of maximum accelerations [1]. The solar radio flux is a quasi-stationary signal [2] from the Sun at centimetric (radio) wavelength due to coronal plasma trapped in the magnetic fields overlying active regions and it originates from atmospheric layers high in the Sun's chromospheres and low in its corona. It changes gradually from day-to-day, in response to the number of spot groups on the disk. The direct and indirect solar influences have effects on short-wave radio communications, satellites for communication and navigation, humans and instruments in space, electrical power transmission, and possibly on weather and human and animal behaviour. Radio intensity levels consist of emission from three sources: from the undisturbed solar surface, from developing active regions, and from short-lived enhancements above the daily level. Rayleigh-Jeans approximation explains the blackbody radiation in the radio region, and the brightness of the radiation is expressed as [3]

$$B_r = 2kT_b\gamma^{-2} \tag{1}$$

where K is Boltzmann constant and T_b is brightness temperature in Kelvin and γ is the wavelength; B_r is expressed in unit of W m^{-2} Hz^{-1} sr^{-2}.

Power flux density (irradiance per bandwidth) is strictly defined as the integral of (B_r Θ), between the limits f and $f + \Delta f$, where Θ is the solid angle subtended by the source. So power spectral density is

$$Fs = \{Br.\,\Theta\}_{(f,f+\Delta f)} \tag{2}$$

Henceforth, the power received at the antenna due to solar radiation depends on the effective area A_C of the antenna and antenna temperature T_A. So the effective equation for calculating the solar power flux density from a given antenna temperature is given by

$$F_s = 2kT_A\frac{L}{A_c} \tag{3}$$

where L is a dimensionless correction factor related to the antenna's response shape and to the diameter and the temperature distribution across the source.

II. Signal Interpretation

Solar flux density at *2800* MHz has been recorded daily by radio telescopes near Ottawa (February 14, 1947-May 31, 1991) and Penticton, British Columbia, Dominion Radio Astrophysical Observatory (since the first of June, 1991). Each day, levels are determined at local noon (1700 GMT at Ottawa and 2000 GMT at Penticton) and then these are corrected within a few percent for factors such as for antenna, atmospheric absorption, bursts in progress, and background sky temperature [4]. Its unit is in solar flux units (SFU) (1 SFU = 10-22 W m^{-2} Hz^{-1}). Solar radio flux represents a measure of diffuse, non- radiative heating of the coronal plasma trapped by magnetic fields over active regions. It is an excellent indicator of overall solar activity levels and correlates well with solar UV emissions [5].

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In this context, an effort has been made to reveal the memory process hidden in this irregularly sampled discrete time quasi-stationary signal. Here, we applied the Savitzky-Golay algorithm [6, 7, 8] of non linear phase filter in order to reduce noisy effect in the time variant signal of solar radio flux during the time span of 29th October, 1972 to 28th February, 2013 and Finite Variance Scaling Method [9, 10] to find the corresponding Hurst exponent.

III. Theoretical Investigation

A. Signal Filtration: Savitzky-Golay Nonlinear Phase Filter

This method [6, 7, 8] is preferred for denoising and smoothing of the sampled signal as in addition to the effective removal of noise the positional importance of the signal remains safe with a satisfactory level. [11, 12]

Savitzky and Golay [6] proposed that fitting a polynomial to a set of input samples and then evaluating the resulting polynomial at a single point within the approximation interval is equivalent to discrete convolution with a fixed impulse response. The basic idea of the algorithm considers a sequence of sampled signal $x(n)$ for the moment the group of $(2M+1)$ samples centered at $n = 0$. Eventually, we can obtain the coefficients of the corresponding polynomial:

$$y(n) = \sum_{n=-m}^{m} (p(n) - x[n])^2 \tag{4}$$

Where

$$p(n) = \sum_{k=0}^{n} a_k n^k \tag{5}$$

where a_k's are the weighted functions. This polynomial expression minimizes the mean-squared approximation error for the group of input samples centering at $n = 0$, that the output value is just equal to the 0th polynomial weight. This leads to nonlinear phase filters, which can be useful for smoothing at the ends of finite-length input sequences. The output at the next sample is obtained by shifting the analysis interval to the right by one sample, redefining the origin to be the position of the middle sample of the new block of $(2M+1)$ samples, and repeating the polynomial fitting and evaluation at the central location. This can be repeated at each sample of the input, each time producing a new polynomial and a new value of the output sequence $y[n]$. Savitzky and Golay [6] showed that at each position, the smoothed output value obtained by sampling the fitted polynomial is identical to a fixed linear combination of the local set of input samples. The output samples can be computed by a discrete convolution of the form:

$$y[0] = \sum_{n=-m}^{m} h[m]x[n-m] = \sum_{m=n-m}^{n+m} h[n-m]x[m] \tag{6}$$

B. Finite Variance Scaling Analysis: Hurst Exponent

Hurst exponents are widely used to characterize stochastic processes and are often associated with the existence of auto-correlations that describe memory process in signals [13, 14]. Finite Variance Scaling Method (FVSM) is a popular tool to evaluate the Hurst exponent. A well known version of FVSM is the Standard Deviation Analysis (SDA) [14, 15], which is based on the evaluation of the cumulative standard deviation $SD(t_j)$ ($j=1, 2, ..., n$) of the variables $x(t_i)$: $i=1, 2, ..., j$. In a time series $\{x(t_i)\}$ observed at the instants t_i for $i=1, 2, ..., n$ it yields

$$S.D(t_j) = \left[\frac{\sum_{i=1}^{j} x^2(t_i)}{j} - \left\{\frac{\sum_{i=1}^{j} x(t_i)}{j}\right\}^2\right]^{1/2} \tag{7}$$

for $j = 1,2\ldots n$

Eventually it is observed

$$SD(t) \propto t^H \tag{8}$$

This exponent H is known as Hurst Exponent. Usually for a discrete time variant signal H lies between 0 and 1. The value of $H=0$ corresponds to white noise. If for a discrete time variant signal we have $0<H<0.5$ it is suggested that the signal shows anti-persistent behaviour i.e. the signal is governed by a short memory process. In this case the signal may have some underlying trends and it may be multi-periodic and/or pseudo-periodic in nature. The value $H=0.5$ represents the ideal case of chaotic behaviour. If we have $0.5<H<1$ the signal is persistent in nature i.e. it is then governed by a long memory process. For $H=1$ we have a smooth signal.

IV. Results And Discussion

We have applied the Savitzky-Golay filter on the solar radio flux data during the time period 29th October, 1972 to 28th February, 2013 [4]. Figure 1 depicts the original data against time and Figure 2 exhibits the filtered data against time. Figure 3 represents the curve SD vs. t (days) from which we can evaluate the value H using (8) by means of taking the gradient of the best-fitted straight line against the plot of $log\ SD(t)$ vs. $log\ t$.

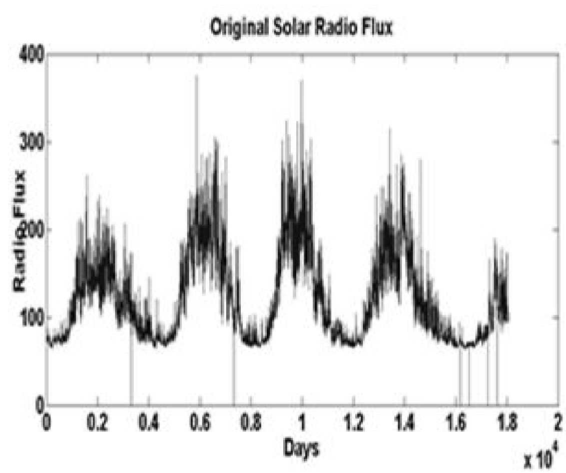

Figure 1: Original signal

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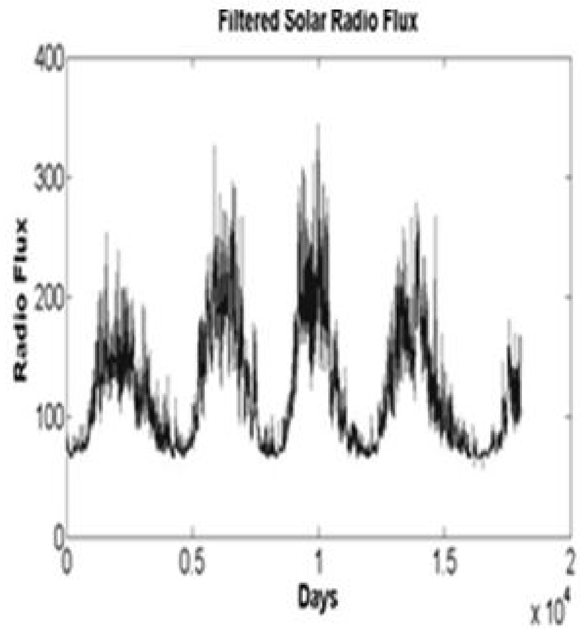

Figure 2: Filtered signal

Calculation yields the value of *H* as 0.39952 which indicates that the present solar radio flux data is governed by a short memory process.

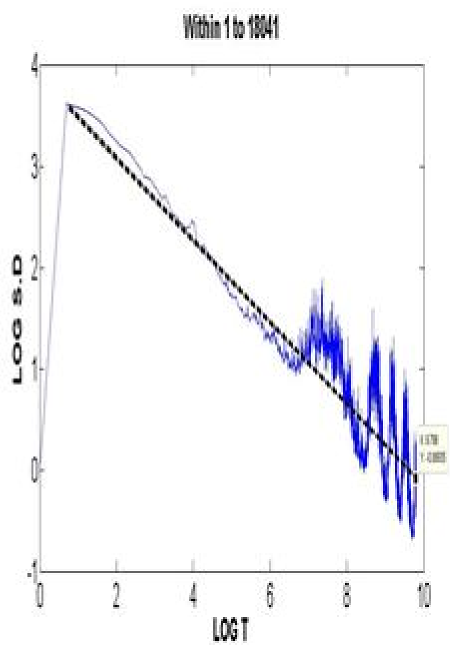

Figure 3: log (SD) vs log (time)

Conclusion

In the present work our result exhibits that the memory of the discrete signal of solar radio flux is short in nature which may in turn suggest the multi-periodic and/or pseudo-periodic behaviour of the present signal. Our future study will be in this direction to incorporate a suitable spectral analysis to identify the periods and/or pseudo-periods in the present signal. Frequency domain analysis for the present signal will certainly help us to gather some information regarding the internal dynamics of the Sun as the present signal certainly bears some signature and characteristics of the same. The future study will be also in the direction of the model identification for the present signal and dealing with the forecasting and validation.

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